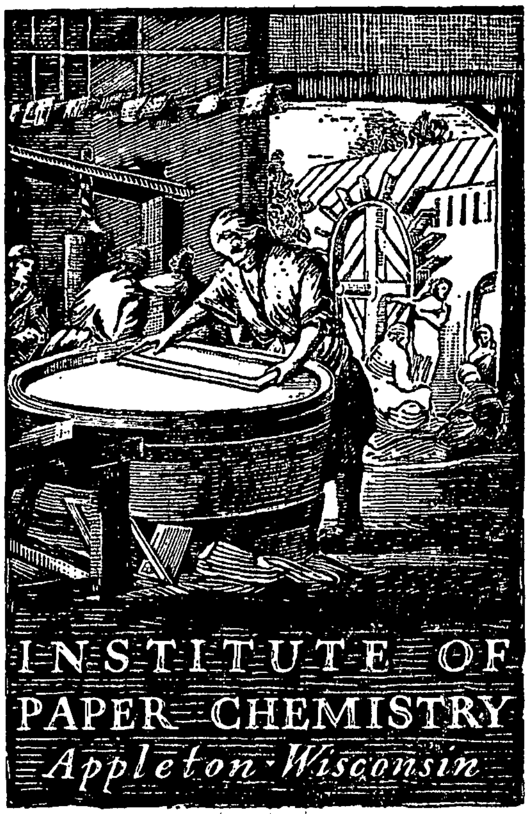

A STUDY OF THE RELATIONSHIP BETWEEN BASIC FIBER AND SHEET PROPERTIES AND SACK PERFORMANCE

Project 2033

Report Twenty-Four

A Progress Report

to

MULTIWALL SHIPPING SACK PAPER MANUFACTURERS

July 22, 1963

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

STUDY OF THE RELATIONSHIP BETWEEN BASIC FIBER AND SHEET PROPERTIES AND SACK PERFORMANCE

SUMMARY

A study has been carried out to determine if consideration of basic fiber and sheet properties such as fiber-breaking stress and bonded area would improve the prediction of sack performance. The study has been pursued in two parts. Part I involved a statistical analysis of the relationship of fiber and sheet properties to sack performance obtained on the twenty-six samples of sack paper—twelve flat kraft and fourteen extensible sack papers from the second fabrication program. The results obtained in Part I may be summarized as follows:

1. The fiber breaking stress for the regular or flat kraft samples was relatively constant for all the samples.

2. Simple correlation involving fiber breaking stress and zero-span tensile indicated that there appeared to be no significant relationship between these properties and sack performance. Further, the correlation coefficients were substantially lower than were obtained with the "better" conventional paper tests such as tensile energy absorption, T.A. impact fatigue, and Frag.

3. The specific scattering coefficient, which is a measure of the unbonded area, appeared to be significantly related to face and butt drop performance for extensible sacks but not to the regular sacks.

4. When the basic fiber strength was used in a multifactor relationship with those paper properties which individually appear to be related to sack performance, there was little improvement in the relationship. The same was true when fiber breaking stress and scattering coefficient were combined in a two-factor multiple.

5. When scattering coefficient was combined with those paper properties, which were best related to sack performance, the relationship appeared to be improved as measured by the magnitude of the correlation coefficients.

6. The best prediction appeared to be obtained with a three-factor multiple involving scattering coefficient, in-machine stretch, and cross-machine stretch. Predictions of face and butt drop sack performance for regular sack kraft agreed on the average with the observed values within 6.0 and 7.5%, respectively. In the case of the extensible kraft samples, the average agreement between predicted and observed face and butt drop performance was 7.0 and 10.4%, respectively.

7. The results of this part of the study indicated that the relationship between bonding, stretch, and sack performance should be investigated more fully.

Part II involved the application of the statistical approach used in Part I when applied to the data obtained in the first fabrication program reported in Progress Report Twelve. The results obtained are as follows:

1. Prediction of face and butt drop performance by means of a three-factor relationship involving scattering coefficient and stretch (in and cross) were vastly inferior to the prediction obtained in Part I.

2. The predictions based on the three-factor relationship were not materially better than stretch alone.

3. The present data do not permit resolution of the anomaly.

INTRODUCTION

The results obtained on the comparative study of the performance of sacks fabricated from flat and extensible sack papers have been reported in Progress Report Twenty-One, Project 2033, dated October 1, 1962 (1). Statistical analysis of the results indicated that, on the basis of simple correlation, sack performance appeared to be best related to paper tests involving stretch, tensile energy absorption or fatigue combined with energy absorption such as Frag or Thwing-Albert impact fatigue. The above conclusion is essentially similar to that reached in the previous fabrication program (2). The simple correlations based on consideration of the two different populations, i.e., flat and extensible, which gave the highest degree of correlation are tabulated in Table I. Analysis based on simultaneous consideration of a number of paper properties revealed that, in general, the relationships were improved; however, in most cases, the improvement was not as great as desired for predicting sack paper performance.

The absence of any definitely practical improvement in the paper-sack performance relationship as a result of multiple correlation, and the fact that the majority of the paper properties which appear to be related to sack performance are also interrelated indicated that the sack paper properties employed in Progress Report Twenty-One were not sufficient by themselves to define sack performance to as high a degree as desired. As a result, attention was directed to consideration of other properties which might improve the relationship.

The present study was initiated to determine if consideration of basic fiber or sheet properties such as fiber-breaking stress and bonded area by themselves or in a multiple correlation with other appropriate sack paper properties would improve the prediction of sack performance. The study has been pursued in two parts. The initial work, Part I, is concerned with the correlation of the above-mentioned fiber or sheet properties and sack performance separately, and in combination with other sack paper properties using the results obtained in the second fabrication program and reported in Progress Report Twenty-One (1). The multiple correlation involving scattering coefficient and stretch in both directions permitted a prediction of sack performance to a degree of precision which was most encouraging.

As a result of the encouraging relationships obtained with the three-factor multiple mentioned above, it was decided to explore further the usefulness of scattering coefficient by applying the same general analysis to the data obtained in the first fabrication program (2). Part II is concerned with this extension of the study.

When a sack is dropped on its face or butt as in the laboratory performance tests employed in this study, the walls of the sack are stressed. The degree of stressing will depend among other things on the height of the drop, the characteristics of the commodity, and the "free" volume in the sack. Stress may be of three types, tension, compression, or shear. These may act separately or collectively in a system as complicated as an impacting sack. It is generally accepted, based on work carried out in various laboratories, that the paper in a sack is subjected to tensional stresses when impacted. The behavior of sacks at the moment of impact (3) the stress-strain characteristics of the sack paper before and after impact (4, 5), and the marked dependency of sack performance on energy absorption reported in Progress Report Twenty-One and others (2, 6-10) strongly indicate that tension stresses play an important role in sack failure resulting from internally generated stresses.

It has long been recognized that the strength properties of a sheet are dependent on the intrinsic strength of the fibers and the number and strength

TABLE I

CORRELATION OF PAPER AND SACK PERFORMANCE

(Simple correlation coefficients)

Test Property	Correlation Coefficient			
	Regular		Extensible	
	Face	Butt	Face	Butt
Stretch, in	0.68	0.59	0.48	0.40
cross	0.75	0.58	0.43	0.43
T.E.A., in	0.65	0.47	0.46	0.41
cross	0.70	0.83	0.66	0.78
Frag, in	0.56	0.42	0.83	0.91
cross	0.80	0.93	0.36	0.49
Impulse, in	0.55	0.44	0.46	0.46
cross	0.70	0.76	0.58	0.66
T.A. impact fatigue	0.69	0.59	0.82	0.83

of the bonds. Further, in a relatively recent study (11) it was found that the hydrodynamic swollen specific volume, zero-span tensile strength, and specific scattering coefficient account for 95% of the variation in tensile strength for a number of different pulps over a wide range of freeness. Because of the above association and the apparent importance of tension stresses in sack performance, it was decided to determine if these more basic fiber and sheet properties would improve the precision of the relationship between sack paper properties and sack performance.

The hydrodynamic swollen specific volume is the apparent volume in cubic centimeters per gram of the fiber and its bound water as measured by a permeation or filtration technique. The measurement of this property is made on the original wet fiber since the repulped slurry would not have the same swollen volume. Consequently, this property could not be included in the study as the only source of fiber was in the form of machine-made and dried sheets.

The basic fiber strength desired in this study is the average breaking stress of the fibers. Since the fibers are not aligned in a given direction, the determination of fiber strength must be obtained indirectly or individual fiber strength determined which is most laborious. Van den Akker *et al.* (12), have developed the theoretical relationship between fiber stress and zero-span sheet stress for unoriented sheets which has been confirmed by experimental studies. According to the theory, the zero-span breaking stress should be three-eighths of the breaking stress of individual fibers. Stated in another way, if fibers are Hookean up to the point of rupture, the zero-span test should yield a breaking load equivalent to 3/8 or 37.5% of the load which would be observed if all the fibers were aligned in the direction of loading.

As mentioned, the foregoing applies to unoriented sheets and, therefore, the theory is not applicable to machine-made sheets because of their directionality. However, as a first approximation, the zero-span tensile strength of machine-made regular papers may be interpreted as representing the individual fiber strength component acting in the direction of loading.

In order to obtain the fiber breaking stress, the relationship developed recently by Van den Akker (13) for an oriented sheet was used. This relationship may be expressed as:

$$\sigma = [(8/3)(\rho/W)(9A + 11)/20A]T_x \qquad (1)$$

where ρ = fiber wall density; assumed to be 1.55 g./cc. for present calculations

W = basis weight, g./sq. cm.

T_x = M.D. zero-span tensile, kg./cm.

T_y = C.D. zero-span tensile, kg./cm.

A = ratio T_x/T_y

σ = fiber breaking stress, kg./sq. cm.

It is recognized that one of the important factors which affects paper strength is the amount of interfiber bonding or bonded area that exists in a sheet of paper. It is clear that fiber bonds and hence bonded area play a very important role in paper strength. The amount of bonding in paper may be varied considerably in accordance with the refining and papermaking techniques employed. Various methods of measuring bonded area have been developed; however, they all involve calculating bonded area from a knowledge of the total fiber surface area and the unbonded area in accordance with the following relationship:

$$A_b = A_t - A_o \tag{2}$$

where $\underline{A_b}$ = bonded area

$\underline{A_t}$ = total fiber area

$\underline{A_o}$ = unbonded area

One of the most widely used methods is the optical method such as was used in this study. Several studies involving the specific scattering coefficient calculated in accordance with the Kubelka-Munk theory have shown a close relationship between the unbonded area and specific scattering coefficient by independent means. There have been problems associated with determining the bonded area because of uncertainty in measuring the total fiber area available for bonding. Although difficulty or uncertainty is associated with this determination, in many experimental studies it has been empirically shown that the unbonded area may be treated as the complement of the bonded area.

GENERAL PROCEDURE

As previously mentioned, the purpose of this study was to determine if the consideration of basic fiber and sheet properties such as fiber breaking stress and scattering coefficient would improve the prediction of sack performance.

To this end, zero-span tensile and scattering coefficients were determined on the twenty-six samples used in the study reported in Progress Report Twenty-One. The scattering coefficient was obtained through the use of the Kubelka-Munk relationship based on total transmittance and reflection. The latter was obtained for an infinitely thick pad with a G. E. Recording Spectrophotometer at a wavelength of 650 mmu. The specific scattering coefficient was obtained by dividing the scattering power by the basis weight.

The zero-span tensile was obtained using the method worked out by Wink and Van Eperen (14). Tests were made in each principal direction. The basic fiber property, fiber breaking stress, was obtained by means of the relationship developed by Van den Akker [see Equation (1)].

Equation (1) was used in computing the fiber breaking stress for both the regular and extensible samples. There is grave doubt, however, that the equation is applicable to extensible kraft papers because of the complexities relative to fiber orientation resulting from the process of making paper extensible.

Analysis of the data was carried out by means of statistical analysis involving simple and multiple regression techniques.

DISCUSSION OF RESULTS

PART I. SECOND FABRICATION PROGRAM RESULTS

The specific scattering coefficients, zero-span tensile strength and sack performance data for the twenty-six samples are tabulated in Table II, according to the type of paper, i.e., regular or extensible.

It may be noted that the specific scattering coefficient for the regular kraft samples ranged from 233 to 260, a spread of approximately ± 6.0%. The corresponding spread for the extensible samples was approximately ± 10.5%. Similarly, the zero-span tensile and fiber breaking stress exhibited the following spreads about their respective averages:

	Regular	Extensible
Zero-span tensile, M.D., %	± 13.7	± 13.8
Zero-span tensile, C.D., %	± 7.9	± 11.6
Fiber breaking stress, %	± 4.3	± 10.2

It should be emphasized that the fiber breaking stress for the extensible samples should be interpreted with extreme caution because it is very questionable if the relationship used in calculating fiber stress has any application to extensible samples.

The small spreads exhibited by the specific scattering coefficient and the fiber breaking stress results for the regular kraft papers indicate that these properties are essentially the same in all the samples; therefore, good correlation with sack performance would not be anticipated.

TABLE II

SCATTERING COEFFICIENT AND FIBER STRESS RESULTS

Run	Specific Scattering Coefficient, sq. cm./g.	Zero-Span Tensile, lb./in. M.D.	Zero-Span Tensile, lb./in. C.D.	Fiber Stress, kg./sq. mm.	Sack Performance, safe inches Face	Sack Performance, safe inches Butt
			Regular Sack Paper			
AA	245	74.2 +	59.8	60 +	401	70
BB	262	72.4	56.1	55	370	43
CC	266 Max	70.9	59.9 +	57	435	61
DD	240	79.5	55.0	59	288	39
EE	259	70.5	54.8	55	201	34
FF	260	68.2	58.5	58	222	31
GG	238	68.8 13.9	55.8	55	316	54
HH	243	72.2	59.0	57	296	57
II	248	72.6	57.0	57	338	58
JJ	233 —	72.7	51.2 — 8.7	55	487	75
KK	237	60.3 —	56.9	53 —	262	58
LL	253	71.5	59.2	59	281	56
Av. =	249	8538/12 = 71.2	6832/12 = 56.9	680/12 = 57		
	33		Extensible Sack Paper[a]			
$A_s = A_E - A_o$ MM	239	53.9	56.1	50.2	855	108
NN	234	49.3	57.2 +	45.1	987	91
OO	232	48.2	55.4	44.1	1144	122
PP	240	59.1	51.9	50.4 +	781	73
QQ	234	55.5 15.0	45.6	43.6	1023	97
RR	220	46.7 —	50.6	44.6	1288	127
SS	271	59.2	50.0	49.2	438	41
TT	272	56.4	46.0 —	45.9	565	51
UU	260	53.2	48.9	44.3	585	59
VV	235	49.8	46.4 11.2	41.0 9.4	1038	112
WW	246	53.0	50.8	45.6	807	66
XX	258	61.7 +	56.3	49.7	650	65
YY	261	55.9	47.3	44.4	727	70
ZZ	220	47.6	49.6	43.9	951	95
Av. =	3422/14 = 244	7495/14 = 53.5	7121/14 = 50.9	6420/14 = 45.8		

[a]Zero-span tensile and hence fiber breaking stress on extensibles may be meaningless because of (1) fibers not aligned in x-y plane—may have segments in Z direction. Also, caliper was higher than ideal. (40-70 g./M^2 ideal)

SIMPLE CORRELATION

The simple correlations of specific scattering coefficient, zero-span tensile and fiber breaking stress and sack performance are tabulated in Table III together with the "better" simple correlation coefficients reported in Progress Report Twenty-One. It may be noted that specific scattering coefficient, which is a measure of the unbonded fiber area in the sheet, is poorly correlated with regular sack performance but seems to be well related to extensible sack performance. At the 5% level of significance, the coefficients must be greater than 0.58 and 0.53, respectively, for $\underline{N} = 12$ and $\underline{N} = 14$, respectively, to be significantly different from zero. The basic fiber property, fiber breaking stress, does not appear to be significantly correlated to sack performance. This, of course, was anticipated from the low spread in the stress values. The zero-span tensile properties do not appear to be related in this study to the performance of regular sack. The relationships obtained with the machine direction zero-span of extensible papers do not appear to be realistic because of the inverse relationships which at the moment are not justifiable.

As an interesting side light, it appears that since the fiber stress for all the regular samples were essentially constant, it indicates that the difference in sack performance is due to what is done to the fiber in the process of manufacture of the paper rather than differences in the intrinsic strength of the fibers.

When the simple correlation coefficients obtained in this study are compared with the "better" results obtained in Progress Report Twenty-One, it may be seen that with the exception of specific scattering coefficient for extensible paper the relationships are of no predictive value. The relationship of specific scattering coefficient and extensible sack performance is somewhat better than T.A. impact fatigue and possibly slightly better than in-machine Frag; however,

TABLE III

SIMPLE CORRELATION COEFFICIENTS

Independent Variable	Dependent Variable, safe inches Regular $\underline{N}$ = 12[a] Face	Butt	Extensible $\underline{N}$ = 14[a] Face	Butt
Specific scattering coefficient	0.16	0.49	-0.91	-0.87
Fiber breaking stress	0.18	0.10	-0.47	-0.39
Zero-span tensile, in	0.30	-0.02	-0.77	-0.74
cross	0.16	0.00	0.14	0.22
Stretch, in	0.68	0.59	0.48	0.40
cross	0.75	0.58	0.43	0.43
T.E.A., in	0.65	0.47	0.46	0.41
cross	0.70	0.83	0.66	0.78
Frag, in	0.56	0.42	0.83	0.91
cross	0.80	0.93	0.36	0.49
Impulse, in	0.55	0.44	0.46	0.46
cross	0.70	0.76	0.58	0.66
T.A. impact fatigue	0.69	0.59	0.82	0.83

[a]For $\underline{N}$ = 12 and $\underline{N}$ = 14, the correlation coefficients must be greater than 0.58 and 0.53, respectively to be significantly different from zero.

when regular kraft papers are considered, it is of no predictive value whereas both Frag and T.A. impact fatigue appear to have merit, especially the former.

MULTIPLE CORRELATION

In order to determine if fiber breaking stress and/or scattering coefficient would add precision to the "better" single factor relationships reported in Progress Report Twenty-One, these properties have been combined in a number of multifactor relationships. The correlation coefficients are given in Table IV together with the corresponding data from Progress Report Twenty-One. When the results obtained in Tables III and IV are compared, it may be seen that the use

TABLE IV

MULTIPLE CORRELATION COEFFICIENTS

Regression No.	Independent Variable	Dependent Variable: Regular Face	Regular Butt	Extensible Face	Extensible Butt
1	Fiber stress and impulse in, and impulse cross	0.80	0.80	0.62	0.66
2	Fiber stress and T.E.A. in, and T.E.A. cross	0.84	0.86	0.74	0.82
3	Fiber stress and stretch in and stretch cross	0.91	0.75	0.61	0.55
4	Fiber stress and T.A. impact fatigue	0.70	0.59	0.82	0.83
5	Fiber stress and Frag in and Frag cross	0.81	0.95	0.85	0.91
6	Fiber stress and specific scattering coefficient	0.79	0.50	0.93	0.88
7	Scattering coefficient and zero-span in and cross	0.35	0.55	0.92	0.88
8	Scattering coefficient and impulse in and cross	0.82	0.82	0.96	0.95
9	Scattering coefficient and T.E.A. in and T.E.A. cross	0.85	0.89	0.94	0.95
10	Scattering coefficient and stretch in and stretch cross	0.93	0.91	0.94	0.90
11	Scattering coefficient and T.A. impact fatigue	0.72	0.64	0.95	0.93
12	Scattering coefficient and Frag in and Frag cross	0.89	0.95	0.95	0.96
13[a]	T.E.A. in and T.E.A. cross	0.84	0.86	0.73	0.82
14[a]	(T.E.A. in)(T.E.A. cross)/T.E.A. in + T.E.A. cross	0.84	--	0.74	--

[a]From Progress Report Twenty-One.

of fiber stress in a multifactor relationship did not result in a marked improvement. Regression 1 involving fiber stress and impulse was only slightly better than impulse cross by itself. Regression 2 involving fiber stress and tensile energy absorption (T.E.A.) was only slightly better than T.E.A. cross by itself and not as good as a two factor involving T.E.A. in and cross (see Regression 14, Table IV). Regression 3 was somewhat better for regular paper but only slightly better than stretch cross for the extensible samples. Combining fiber stress (Regression 4) with T.A. impact fatigue resulted in no improvement over T.A. impact by itself. The same may be said relative to Frag and fiber stress (Regression 5). The two-factor multiple involving specific scattering coefficient and fiber stress was approximately the same for the extensible samples as specific scattering coefficient by itself. In the case of the regular samples, there was some improvement in the magnitude of the coefficient; however, it is questionable if the improvement is significant.

When the correlations involving the specific scattering coefficient are considered, it may be noted that all of the multiples exhibited an improvement over the simple correlations. Regression 8 involving scattering coefficient and impulse exhibited considerable improvement in the magnitude of the correlation coefficient. When T.E.A. in and cross is combined with scattering coefficient (see Regression 9) the coefficients were considerably higher than when T.E.A. was used in a simple regression. When compared against the two-factor relationship involving T.E.A. in and cross, (see Regression 14) the improvement is mainly with the extensible kraft samples. Including scattering coefficient with stretch in and cross caused a marked improvement in the correlation coefficient (see Regression 10). The inclusion of scattering coefficient with T.A. impact fatigue (see Regression 11) improved the relationship only slightly. The same may be said relative to Regression 12 in which Frag in and cross is combined in a three-factor relationship with scattering coefficient.

The equations for Regressions 8 through 12 are given in Table V. Inasmuch as scattering coefficient is a measure of the unbonded area, and unbonded area may be considered as the complement of bonded area, it intuitively would be expected that sack performance would decrease with increase in unbonded area and, hence, the coefficient of the scattering coefficient in the multiple regression should bear a negative sign. The other paper properties, on the other hand, should be directly related to sack performance. It may be observed that only Regression 10 involving stretch, in and cross, plus scattering coefficient meet the requirements intuitively established.

In order to obtain a comparison of the predictive ability of Regression 10, the equations given in Table V for the three-factor relationship have been used to compute the predicted sack performance. The predicted and observed sack performance values are given in Table VI. It may be observed that the average difference between predicted and observed for face drop performance was 6.0 and 7.5%, respectively, for regular and extensible sack papers. The corresponding results for butt drop were 7.0 and 10.4%. The per cent of comparisons, i.e., predicted-observed, within arbitrary ranges are tabulated in Table VII.

Although the regression equations for each type of paper appear to vary considerably, the data for the twelve regular and fourteen extensible sacks were combined and analyzed. The regression equations together with a comparison of predicted and observed sack performance are given in Table VIII. It may be noted that the regressions for the combined data (Regressions 13 and 14) did not predict sack performance of flat kraft nearly as well as the regression equations based on flat kraft—Regression 10. In the case of the extensible sacks, the predictions were not quite as good as when the regression was based on only the extensible sacks.

TABLE V

REGRESSION EQUATIONS

Regression Number	Regular	Extensible
	Face Drop	
8	$Y_f = 1.68SC + 50.09I_x + 62.54I_y - 940.75$	$Y_f = -11.20SC + 3.70I_x + 53.26I_y + 2985.03$
9	$Y_f = 1.14SC + 809.35T.E.A._x + 600.02T.E.A._y - 504.43$	$Y_f = -10.33SC + 200.84T.E.A._x + 614.83T.E.A._y + 2766.56$
10	$Y_f = 1.69SC + 279.21S_x + 100.13S_y - 8.44$	$Y_f = -11.23SC + 18.81S_x + 88.68S_y + 3005.85$
11	$Y_f = 1.49SC + 8.75T.A. - 183.15$	$Y_f = -9.25SC + 6.41T.A. + 2758.26$
12	$Y_f = 3.58SC + 0.22F_x + 0.82F_y - 1043.55$	$Y_f = -9.04SC + 0.88F_x - 0.31F_y + 2581.27$
	Butt Drop	
8	$Y_b = -0.25SC + 3.63I_x + 9.71I_y + 14.23$	$Y_b = -1.15SC - 0.05I_x + 9.57I_y + 274.65$
9	$Y_b = -0.25SC + 57.80T.E.A._x + 111.09T.E.A._y + 45.36$	$Y_b = -0.94SC + 15.04T.E.A._x + 136.81T.E.A._y + 217.54$
10	$Y_b = 0.66SC + 38.83S_x + 13.23S_y + 114.88$	$Y_b = -1.24SC + 1.07S_x + 11.04S_y + 325.39$
11	$Y_b = 0.34SC + 0.83T.A. + 125.38$	$Y_b = -0.89SC + 0.88T.A. + 254.47$
12	$Y_b = -0.08SC - 0.03F_x + 0.15F_y - 2.50$	$Y_b = -0.80SC + 0.14F_x + 8.49F_y + 8.49$

SC = Scattering coefficient.

I_x, I_y = Impulse in and cross, respectively.

$T.E.A._x$, $T.E.A._y$ = Tensile energy absorption in and cross.

S_x, S_y = Stretch in and cross.

$T.A.$ = T.A. impact fatigue.

F_x, F_y = Frag in and cross.

TABLE VI

COMPARISON OF OBSERVED AND PREDICTED SACK PERFORMANCE
(Regression 10)

Run No.	Face Drop, safe inches Predicted	Face Drop, safe inches Observed	Face Drop, safe inches Difference	Butt Drop, safe inches Predicted	Butt Drop, safe inches Observed	Butt Drop, safe inches Difference
			Regular			
AA	421	401	+20	68	70	-2
BB	346	370	-24	50	43	+7
CC	421	435	-14	58	61	-3
DD	267	288	-21	49	39	+10
EE	215	201	+14	34	34	0
FF	223	222	+1	35	31	+4
GG	303	316	-13	55	54	+1
HH	252	296	-44	46	57	-11
II	337	338	-1	56	58	-2
JJ	463	487	-24	79	75	+4
KK	270	262	+8	58	58	0
LL	333	281	+52	52	56	-4
Av., %[a]			6.0			7.5
			Extensible			
MM	875	855	+20	90	108	-18
NN	931	987	-44	93	91	+2
OO	994	1144	-150	97	122	-25
PP	850	781	+69	87	73	+14
QQ	982	1023	-31	99	97	+2
RR	1260	1288	-28	127	127	0
SS	452	438	+14	42	41	+1
TT	542	565	-23	51	51	0
UU	732	585	+147	69	59	+10
VV	1001	1038	-37	112	112	0
WW	808	807	+1	79	66	+13
XX	612	650	-38	56	65	-9
YY	677	727	-52	65	70	-5
ZZ	1122	951	+171	118	95	+23
Av., %[a]			7.0			10.4

[a]Without regard to sign.

TABLE VII

COMPARISON OF AGREEMENT BETWEEN PREDICTED AND OBSERVED

	Per Cent of Comparison Within				
	0 - 3%	3 - 5%	5 - 10%	10 - 15%	15 - 20%
Face drop, regular	25	58	92	92	100
Face drop, extensible	29	57	79	100	--
Butt drop, regular	42	75	75	100	--
Butt drop, extensible	43	43	50	71	71

One of the disturbing factors associated with this study is that separate regression equations are necessary for regular and extensible papers. This may be due in part to the necessity of using a complementary property, i.e., unbonded area, in place of bonded area.

PART II. FIRST FABRICATION PROGRAM RESULTS

Inasmuch as the relationship developed in Part I between sack performance and the three sack paper properties, i.e., machine-direction stretch, cross-machine stretch, and scattering coefficient, appeared to be of a relatively high order, it seemed desirable to investigate more fully the influence of scattering coefficient as an aid in predicting sack performance. For this purpose, it was decided to use the data obtained in the first fabrication program (2) as these data represent an entirely different population. In addition, all the data were available except scattering coefficient.

It may be recalled that the first fabrication program involved twenty different samples of flat or regular sack kraft paper which were fabricated into three-ply cement size, pasted and sewn sacks. Only the data obtained on the pasted sacks were analyzed in Part II. The scattering coefficients were obtained on specimens of the paper cut from the pasted sacks which had been stored in the

TABLE VIII

COMPARISON OF OBSERVED AND PREDICTED SACK PERFORMANCE
(Combined Regular and Extensible, N = 26)

Run No.	Face Drop[a] Predicted	Face Drop[a] Observed	Face Drop[a] Difference, %[c]	Butt Drop[b] Predicted	Butt Drop[b] Observed	Butt Drop[b] Difference, %[c]
			Regular			
AA	381	401	-5.0	58	70	-17.1
BB	251	370	-32.0	41	43	-4.7
CC	365	435	-16.1	52	61	-14.8
DD	338	288	+17.4	56	39	+43.6
EE	159	201	-20.9	33	34	-2.9
FF	164	222	-26.1	33	31	+6.5
GG	431	316	+36.4	66	54	+22.2
HH	300	296	+1.4	51	57	-10.5
II	286	338	-15.4	48	58	-17.2
JJ	541	487	+11.1	78	75	+4.0
KK	430	262	+64.1	66	58	+13.8
LL	319	281	+13.5	50	56	-10.7
Average			21.6			14.0
			Extensible			
MM	807	855	-5.6	90	108	-16.7
NN	872	987	-11.6	92	91	+1.1
OO	976	1144	-14.7	95	122	-22.1
PP	780	781	-0.1	87	73	+19.2
QQ	952	1023	-6.9	99	97	+2.1
RR	1285	1288	-0.2	126	127	-0.8
SS	453	438	+3.4	46	41	+12.2
TT	627	565	+11.0	56	51	+9.8
UU	835	585	+42.7	73	59	+23.7
VV	992	1038	-4.4	102	112	-8.9
WW	794	807	-1.6	80	66	+21.2
XX	615	650	-5.4	56	65	-13.8
YY	732	727	+0.7	70	70	0.0
ZZ	1056	951	+11.0	108	95	+13.7
Average			8.5			11.8
Overall Average			14.6			12.8

[a]Regression No. 13. Face drop = $1807.1 - 7.99\ SC + 38.75\ S_x + 135.80\ S_y$

[b]Regression No. 14. Butt drop = $270.3 - 1.07\ SC + 1.11\ S_x + 14.13\ S_y$

[c]Based on observed results as reference.

basement of one of the buildings of The Institute of Paper Chemistry. The physical characteristics of the sack paper samples used in this phase are given in Table IX. The statistical analysis used in Part II was the same as was used in Part I for multiple correlation.

The multiple correlation coefficients for scattering coefficient and other sack paper properties, i.e., impact fatigue, Frag, impulse, stretch, and T.E.A., and progressive face drop and butt drop are given in Table X, and the regression equation in Table XI. It may be noted that the correlation coefficients for face drop were relatively low compared to the magnitude of the coefficients obtained in Part I (see Table IV). On the other hand, the butt drop coefficients approached the magnitude obtained in Part I. In order to compare the relative predictability of the multiple regression equations involving scattering coefficient and stretch (in and cross)—as appeared best in Part I—predicted performance based on equations 17 together with observed drop test data are tabulated in Table XII. It may be noted that the average per cent differences between predicted and observed sack performances were vastly greater than were obtained in Part I. In addition, the multiple correlation coefficients based on the three-factor relationship in Part II were only slightly higher than cross-machine stretch by itself. The latter coefficients were 0.53 and 0.52, respectively, for face and butt drop.

The results obtained in Part II certainly do not confirm the trend noted in Part I. However, it would be expected that both face and butt drop performance would be influenced by the bonded area. The results in Part II indicate that the inclusion of scattering coefficient does not improve the prediction—stretch by itself does equally as well. The present data is not sufficient to resolve the anomaly associated with the results obtained in Parts I and II.

TABLE IX

CHARACTERISTICS OF PASTED SACK PAPER - FIRST FABRICATION PROGRAM

Run	T. A. Impact Fatigue, falls	Frag Burst Energy, 10^{-4} kg.m.		Impulse, mN.s		Stretch, %		T.E.A., in. lb./in.^{2}		Scattering Coefficient, sq. cm./g.
		in	cross	in	cross	in	cross	in	cross	
A	13	276	683	7	11	1.4	4.2	0.257	0.652	228
B	21	390	421	9	6	1.6	2.1	0.358	0.292	268
C	34	542	673	9	10	1.7	4.1	0.383	0.590	251
D	26	502	661	10	8	2.0	4.1	0.473	0.567	237
E	35	543	607	11	8	2.0	3.9	0.478	0.495	233
F	32	472	632	10	10	1.8	3.4	0.372	0.488	256
G	27	593	969	9	10	1.8	3.7	0.426	0.679	211
H	17	376	596	8	12	1.6	4.8	0.314	0.648	268
I	13	322	486	6	8	1.3	2.5	0.258	0.404	251
J	11	295	575	6	10	1.3	3.6	0.254	0.588	258
K	23	386	647	8	10	1.7	3.8	0.391	0.585	250
L	20	292	553	6	9	1.4	5.5	0.266	0.604	243
M	25	366	609	9	10	1.7	3.6	0.383	0.534	260
N	12	337	356	8	8	1.4	3.3	0.348	0.421	280 ✓
O	15	346	381	8	5	1.7	2.3	0.382	0.304	281 ✓
P	27	393	635	8	9	1.5	4.2	0.337	0.534	272
Q	26	507	669	10	11	1.9	5.1	0.440	0.678	211 ✓
R	27	430	524	8	8	1.8	2.7	0.379	0.410	220
S	25	387	621	8	9	1.4	3.5	0.333	0.489	222
T	25	309	631	7	9	1.3	5.4	0.258	0.635	231

$\Sigma = 4931$
Av = 246

TABLE X

MULTIPLE CORRELATION COEFFICIENTS

Regression Number	Independent Variable	Dependent Variable	
		Face Drop	Butt Drop
15	Scattering coefficient and T.A. impact fatigue	0.72	--
16	Scattering coefficient and Frag, in and cross	0.49	0.53
17	Scattering coefficient and stretch, in and cross	0.63	0.53
18	Scattering coefficient and T.E.A., in and cross	0.53	0.81
19	Scattering coefficient and impulse, in and cross	0.52	0.80

TABLE XI

REGRESSION EQUATIONS

Regression Number	Face Drop
15	$Y_x = 245.87 - 0.293\ SC + 10.557\ T.A.$
16	$Y_x = 187.74 - 0.117\ SC + 0.141\ F_x + 0.332\ F_y$
17	$Y_x = 26.3 - 0.336\ SC + 149.0\ S_x + 60.59\ S_y$
18	$Y_x = 106.09 - 0.232\ SC + 376.70\ T.E.A._x + 436.26\ T.E.A._y$
19	$Y_x = 245.75 - 0.878 + 24.566\ I_x + 20.09\ I_y$
	Butt Drop
15	-- -- -- --
16	$Y_b = -109.89 + 0.383\ SC - 0.091\ F_x + 0.192\ F_y$
17	$Y_b = 54.21 - 0.076\ SC - 7.27\ S_x + 10.23\ S_y$
18	$Y_b = -53.65 + 0.178\ SC - 21.53\ T.E.A._x + 150.69\ T.E.A._y$
19	$Y_b = -16.00 + 0.015\ SC - 1.35\ I_x + 9.49\ I_y$

SC = Scattering coefficient

I_x, I_y = Impulse, in and cross, respectively

$T.E.A._x$, $T.E.A._y$ = Tensile energy absorption, in and cross

S_x, S_y = Stretch, in and cross

T.A. = T.A. impact fatigue

F_x, F_y = Frag, in and cross

TABLE XII

COMPARISON OF OBSERVED AND PREDICTED SACK PERFORMANCE

Run No.	Face Drop[a]			Butt Drop[b]		
	Predicted	Observed	Difference	Predicted	Observed	Difference
A	418	411	+ 7	74	70	+ 4
B	196	295	- 99	28	32	- 4
C	453	608	-155	69	76	- 7
D	560	494	+ 66	90	46	+44
E	547	465	+ 82	90	42	+48
F	402	476	- 74	61	64	- 3
G	508	326	+182	94	97	- 3
H	466	374	+ 92	64	85	-21
I	181	258	- 77	33	51	-18
J	279	330	- 51	43	76	-33
K	424	489	- 65	66	77	-11
L	522	358	+164	82	61	+21
M	387	434	- 47	57	90	-33
N	240	192	+ 48	28	31	- 3
O	222	303	- 81	26	33	- 7
P	371	536	-165	49	76	-27
Q	676	481	+195	117	65	+52
R	393	417	- 24	75	44	+31
S	358	425	- 67	69	56	+13
T	505	650	- 95	84	77	+ 7
Av., %			23.2			34.2

[a] Regression No. 17
Face drop $= -0.336\ SC + 149.05\ S_x + 60.60\ S_y + 26.3$ (Corr. Coeff. 0.63)

[b] Regression No. 17
Butt drop $= -0.0762\ SC - 7.266\ S_x + 10.23\ S_y + 54.2$ (Corr. Coeff. 0.53)

LITERATURE CITED

1. The Institute of Paper Chemistry. A study of multiwall sack performance. Part II. Comparative performance of sacks fabricated from regular and extensible sack papers and the relationship between sack performance and sack paper properties. Project 2033, Progress Report Twenty-One, Oct. 1, 1962.

2. The Institute of Paper Chemistry. A study of multiwall sack performance. Part I. Relationship between sack performance and sack paper properties. Project 2033, Progress Report Twelve, Feb. 8, 1960.

3. The Institute of Paper Chemistry. Unpublished work.

4. The Institute of Paper Chemistry. Effect of repeated impacts on strength characteristics of sack paper. Project 2033, Progress Report 4, Dec. 15, 1958.

5. Ihrman, C. B., and Anderson, O. Behavior of bag paper under dynamic loading. Part 2. Response to nondestructive mechanical treatment. Svensk Papperstidn. 62, no. 21:790-800(Nov. 15, 1959).

6. Burgstaller, F., and Krause, R. A. Large scale experiments on quality control of bag papers. Das Papier 9, no. 11/12:237-48(June, 1955).

7. Houston, P. L. A new test for lime and cement bag paper. Paper Trade J. 71, no. 11:34-6(1920); Tech. Assoc. Papers 3, no. 1:7-11(1920); Natl. Bureau Standards Tech. Paper No. 187, 1921. 19 p.; C.A. 14:3319; 15:1397, 3745.

8. London, William. Wet-strength papers open new horizons. Wood 2, no. 6:22-4, 42-3(June, 1947); B.I.P.C. 17:664.

9. Hanaya, Morinasa. Studies on the strength of paper and the influence of manufacturing conditions. I. Sack strength and bursting strength. J. Japan Tech. Assoc. Pulp Paper Ind. 11, no. 4:261-5(April, 1957); B.I.P.C. 27:1279; Packaging Abstr. 14:1008.

10. Welsh, Hewitt S. Toughness: new index for paper. Modern Packaging 31, no. 9:221-2, 225, 228, 292(May, 1958).

11. The Institute of Paper Chemistry. Unpublished work.

12. Van den Akker, J. A., Kathrop, A. L., Voelker, M. H., and Dearth, L. R. Importance of fiber strength to sheet strength. Tappi 41, no. 8:416-425(Aug., 1958).

13. Van den Akker, J. A. Unpublished work. The Institute of Paper Chemistry.

14. Wink, W., and Van Eperen, R. The development of an improved zero-span tensile test. Tappi 45, no. 1:10-24(Jan., 1962).

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